Attachment "Fundamentals of Physics", 4th Edition

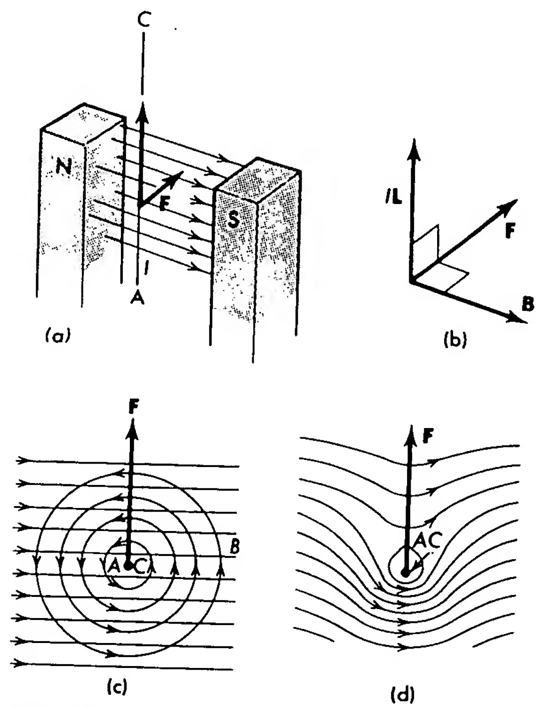


Fig. 25-14 Wire AC between the poles of a magnet carries current I in a magnetic field of strength H and flux density B. (a) Direction of force F on wire is at right angles to the wire and the direction of the magnetic field. (b) Relative directions I, B, and F; these vectors are mutually perpendicular. (c) The two magnetic fields, that due to I and the field B of the magnet; (d) the resultant of these two fields is stronger below AC and weaker above AC. The wire is forced from the stronger to the weaker field.

its magnetic field is circular around the wire and counterclockwise. Below the wire, the two magnetic fields are in the same direction, thus producing a more intense magnetic field; above the wire, the two fields are in opposite directions, thus producing a weak field, as shown in Figure 25-14(d). Experiment shows that the force on AC is upward; that is, the wire is forced from the stronger magnetic field toward the weaker magnetic field. The method outlined above is perfectly general; *whenever a wire carrying current is placed in a magnetic field, the force on the wire will always be directed from the stronger toward the weaker part of the resultant field.*

For example, if a straight wire has a length of 0.5 m in a magnetic field of 1.2 weber/m^2 and is at right angles to this field, then, when the current in it is 15 amp, it will experience a force

$$F = 15 \times 0.5 \times 1.2 = 9.0 \text{ nt}$$

25-9 FORCE BETWEEN TWO PARALLEL WIRES CARRYING CURRENT

Two parallel wires carrying currents will exert forces on each other owing to the interaction of their respective magnetic fields. If the two currents are in the same direction, the force between them will be one of attraction; if the two currents are in opposite directions, the force will be one of repulsion. Figure 25-15 shows the magnetic fields in a plane at right angles to the wires. In Figure 25-15(a), the currents are assumed to be coming out of the paper toward the reader. The magnetic field is circular in a counterclockwise direction around each wire. The two fields are in opposite directions in the space between the wires. The resultant magnetic field is thus weakened in this region, as shown in Figure 25-15(b), and the wires are forced toward each other, each wire going from the stronger to the weaker part of the field. Figure 25-15(c) shows the two magnetic fields between two parallel wires carrying currents in opposite directions. These fields, again, are drawn in a plane perpendicular to the two wires. It will be seen that the fields between the wires are in the same direction, and hence reinforce each other in this region, as shown in Figure 25-15(d). The wires are therefore forced away from each other, the force on each wire being directed from the stronger to the weaker field.

We have already shown that the force on a wire carrying current I in a magnetic field of flux density B is given by

$$F = ILB \qquad (25.19)$$

when I and B are at right angles to each other. We can apply this equation to determine the force between two parallel wires. Let us consider a length L of one wire carrying current I to be in the magnetic field B of the second wire carrying current I' at a distance r from it. The value of B can be found by combining the equation

magnetic flux density

$$\boxed{B = \mu H} \qquad (25.15)$$

and

$$H = \frac{I'}{2\pi r} \qquad (25.11)$$

obtaining

$$B = \frac{\mu I'}{2\pi r} = \frac{\mu}{4\pi}\frac{2I'}{r}$$

Substituting this value of B into Equation (25.19) yields

$$F = \frac{\mu}{4\pi}\frac{2II'L}{r}$$

From this equation we can obtain the value of the force per unit length of wire as

$$\frac{F}{L} = \frac{\mu}{4\pi}\frac{2II'}{r} \qquad (25.20)$$

In a vacuum $\mu = \mu_0$, so that the force per unit length between two parallel wires in a vacuum becomes

$$\boxed{\frac{F}{L} = \frac{\mu_0}{4\pi}\frac{2II'}{r}} \qquad (25.21)$$

The method of defining the unit of current, the *ampere*, is in terms of the force between two parallel wires carrrying equal currents. Thus the measurement of current can be reduced to the measurement of the mechanical quantities, force and distance:

An ampere is that constant current which, when flowing in each of two infinitely long parallel wires that are 1 meter apart in a vacuum, produces a force on each wire of 2×10^{-7} newton per meter of length.

If, in Equation (25.21) we set

$$\frac{F}{L} = 2 \times 10^{-7}\,\frac{\text{nt}}{\text{m}}$$

and

$$I = I' = 1\ \text{amp}$$

$$r = 1\ \text{m}$$

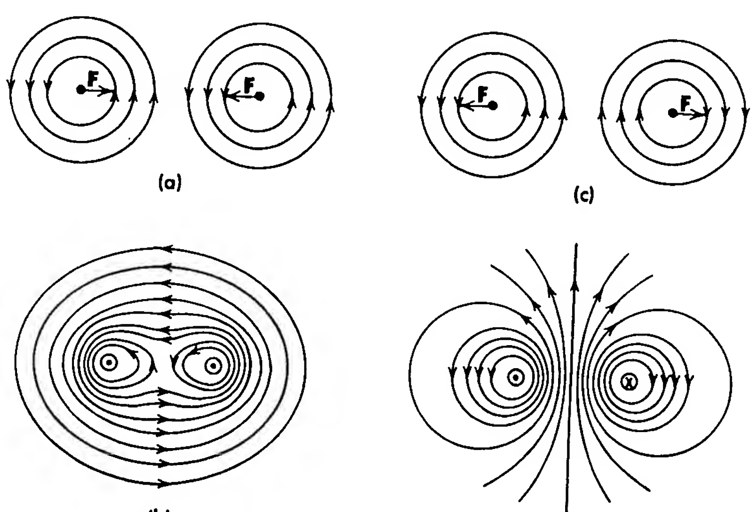


Fig. 25-15 Magnetic field of two parallel wires in a plane at right angles to them (a) when currents are in the same direction out of the paper, (b) the resultant field; (c) currents are in opposite directions, and (d) the resultant field.

we have

$$2 \times 10^{-7}\,\frac{\text{nt}}{\text{m}} = \frac{\mu_0}{4\pi}\,\frac{2 \times 1\ \text{amp}^2}{1\ \text{m}}$$

so that

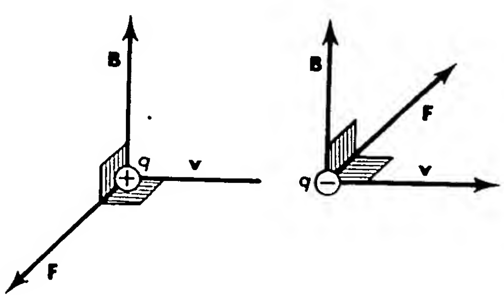
$$\mu_0 = 4\pi \times 10^{-7}\,\frac{\text{nt}}{\text{amp}^2}$$

which is the value we introduced arbitrarily in the previous chapter. The units nt/amp^2 are equivalent to the other units used previously such as weber^2/nt m^2, and nt/amp m.

Equation (25.20) is at the basis for the design of instruments for the most accurate measurements of current; such instruments are called *current balances* and have been in use since the latter part of the nineteenth century. For convenience, circular coils of wire, rather than long straight wires are used in current balances.

25-10 FORCE ON A CHARGE MOVING IN A MAGNETIC FIELD

Rowland's experiment showed that as far as its magnetic effect is concerned, a moving charge is equivalent to a current.



(a) (b)

Fig. 25-16 Force on a charge moving in a magnetic field. (a) When the charge is positive, the force F is directed out of the paper toward the reader; (b) when the charge is negative, F is directed into the paper away from the reader.

We have already shown that if a charge q is moving with a velocity **v**, it can be considered the equivalent of a current element $I\,\Delta\mathbf{s}$; that is,

$$q\mathbf{v} = I\,\Delta\mathbf{s} \qquad (25.3)$$

If this charge is moving with velocity **v** in a magnetic field of flux density **B**, then the force **F** acting on this charge, determined with the aid of Equation (25.17) is

$$F = qvB\sin\theta \qquad (25.22)$$

where θ is the angle between **v** and **B**. In the particular case in which θ is 90°, the above equation becomes

$$\boxed{F = qvB} \qquad (25.23)$$

The force **F** is at right angles to both **B** and **v**. Figure 25-16(a) shows the relative directions of **B**, **v**, and **F** when the charge q is positive, while Figure 25-16(b) shows the directions of these vectors when q is negative. It will be observed that when the velocities of the two charges are in the same direction in the same magnetic fields, the force on the positive charge is opposite to that on the negative charge. If the charge q has a mass m and is acted upon by a force **F**, then, applying Newton's second law,

$$F = ma \qquad (25.24)$$

we get, for the acceleration of the charge,

$$\boxed{a = \frac{qvB}{m}} \qquad (25.25)$$

The acceleration will also be directed at right angles to the directions of **B** and **v**. But we have already seen that in the case of uniform circular motion, the acceleration is always at right angles to the velocity. Hence a charge q, moving with velocity v at right angles to the lines of induction in a uniform magnetic